A CLOUD AND PRECIPITATION RADAR SYSTEM CONCEPT FOR THE ACE MISSION

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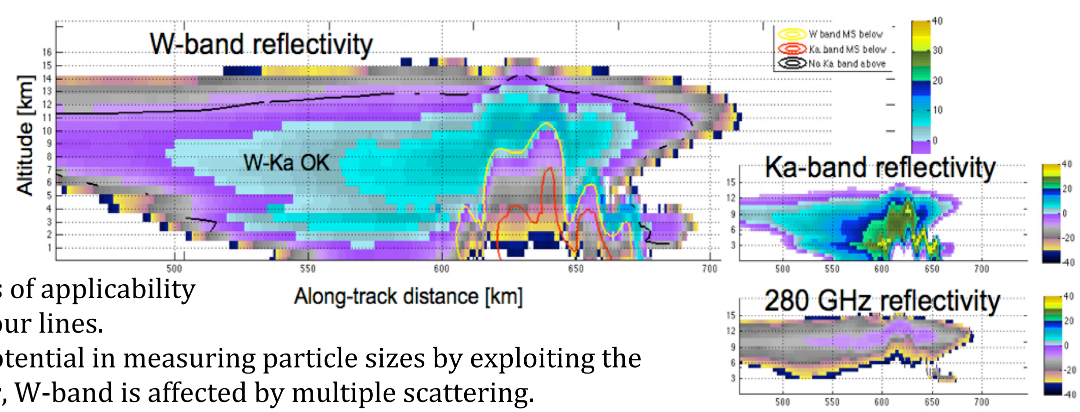
Introduction and Motivation

- NRC Decadal Survey specifically calls for a cross-track scanning, 94 GHz (W-band) and 35 GHz (Ka-band) cloud radar for cloud droplet size, glaciation height, and cloud height; it also indicates use of Doppler to achieve the desired goals.

	Ka-band	W-band
Scanning	goal	goal
Swath width	25 km (goal)	-
Sensitivity	-10 dBZ	-35 dBZ
Doppler accuracy	1 m/s (0.5 m/s goal)	0.4 m/s (0.2 m/s goal)
Horizontal Resolution	2 km	1 km
Vertical Resolution	250 m	250 m
Data window	25 km	25 km

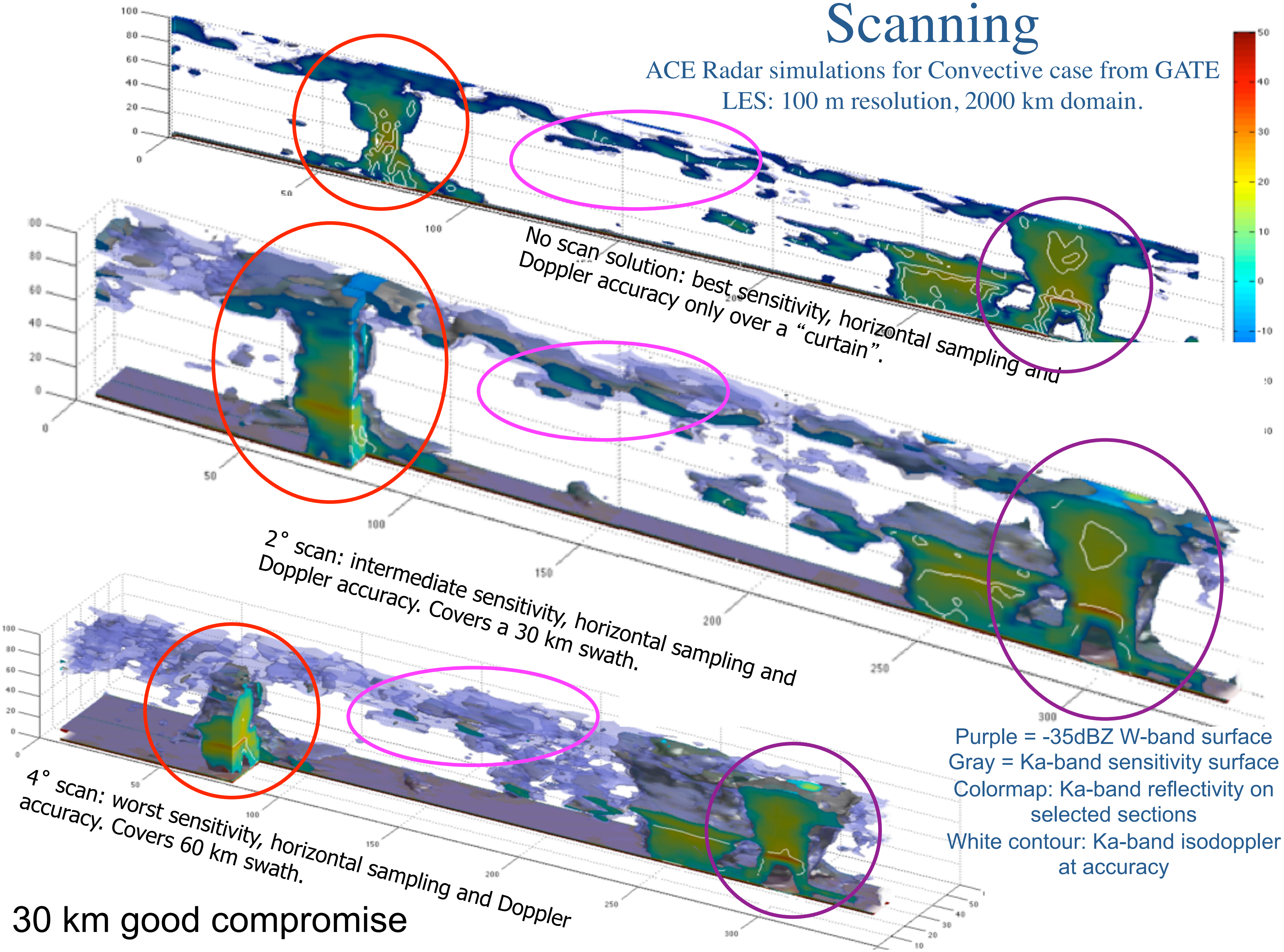
ACE Radar Requirements (ACE SWG)



Simulated ACERAD: W band reflectivity, vertical section across a mid-latitude frontal system. Regions of applicability of dual-frequency algorithms are identified by contour lines.
Above the black contour, only the pair W-EHF has potential in measuring particle sizes by exploiting the differential Mie scattering; below the yellow contour, W-band is affected by multiple scattering.

Scanning

ACE Radar simulations for Convective case from GATE
LES: 100 m resolution, 2000 km domain.



Purple = -35dBZ W-band surface
Gray = Ka-band sensitivity surface
Colormap: Ka-band reflectivity on selected sections
White contour: Ka-band isodoppler at accuracy

30 km good compromise

System Design Trades

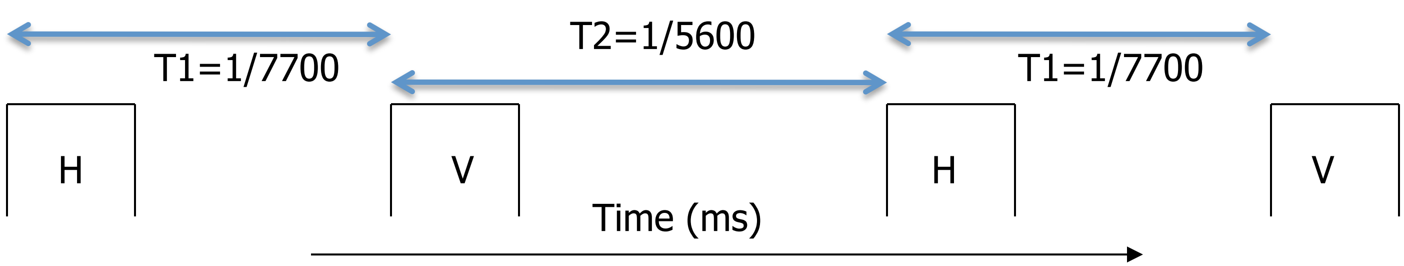
- Higher frequencies -> better sensitivity, but more attenuation
  - Ka-band for light precipitation and heavier clouds
  - W-band for clouds
  - Also investigating 280 GHz technology for estimating ice particle size
- Shorter pulse length -> better range resolution, but reduced SNR
  - 1.67 microseconds for 250 m resolution (same as GPM and TRMM)
- Cross-track scanning -> larger swath, but fewer pulses to integrate
  - Scanning requires challenging technology at higher frequencies
  - Choose scanning at Ka-band, nadir-pointing at W-band
- Doppler capability requires large antenna along-track and/or high PRF
  - Antenna 2.5 m x 5 m
  - Too high PRF creates range ambiguities
  - Too low PRF creates Doppler ambiguities
- Higher duty cycle -> better sensitivity but more spacecraft power
- Dual-polarization
  - Useful for discriminating particle phase
  - Can be used to reduce ambiguities
  - Creates need for polarization switching

Ambiguity Reduction Approaches

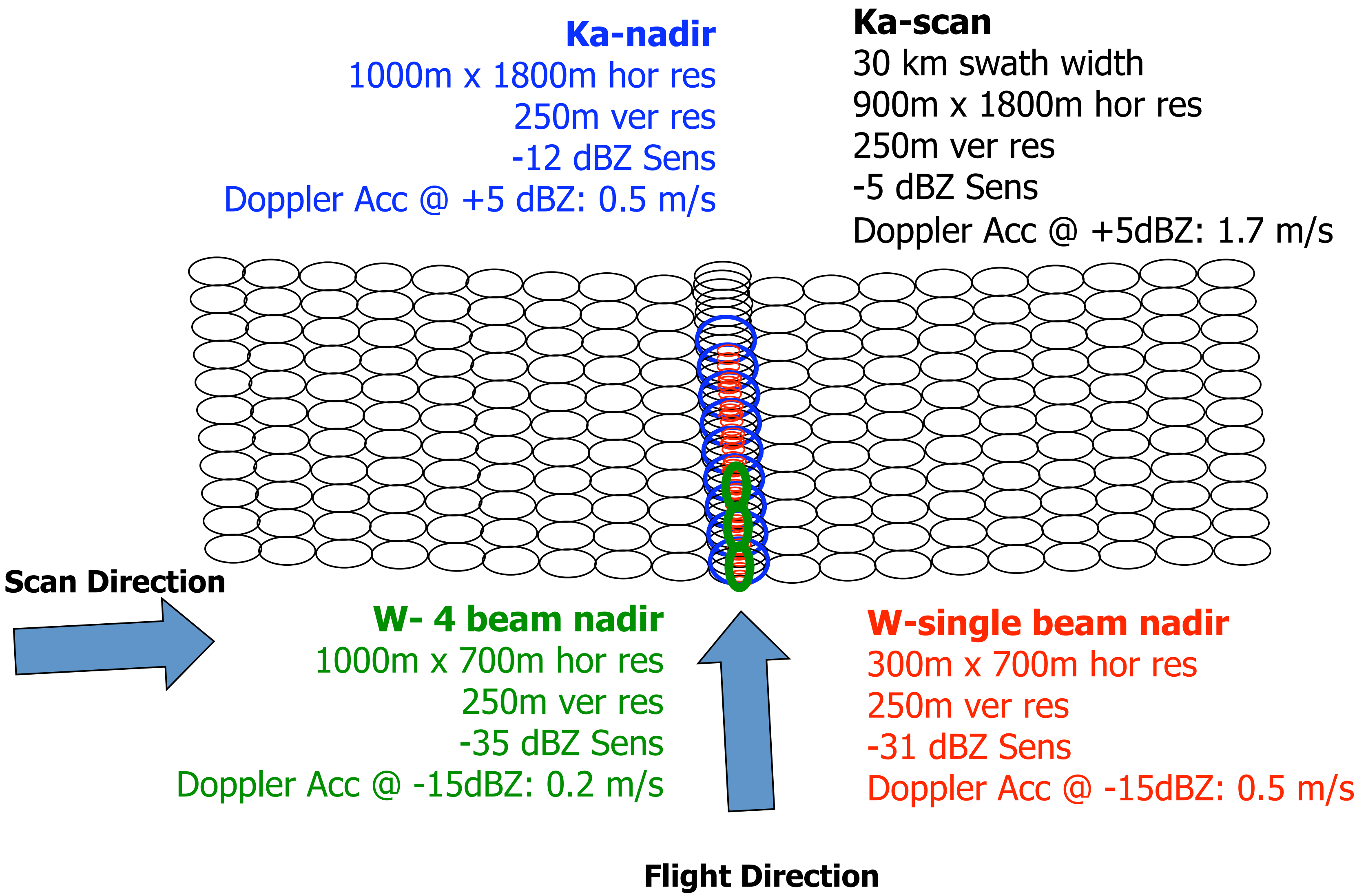
- Basic strategy: encode or tag pulses so that ambiguous returns can be separated
- Alternating polarization
  - Overlapping H and V returns can be separated by antenna/receiver
  - Dual-pol science objectives could be met by measuring the correlation between co-pol returns
- Phase coding
  - Successive pulses are multiplied by a phase shift that is constant throughout the pulse
  - The received signal is recovered by multiplication with the complex conjugate of the transmit code
  - Ambiguity cancellation relies on small phase errors in system (50 dB reasonable)
- Staggering of pulse repetition interval (PRI)
  - Alternating pulses are delayed
  - This creates two PRIs: T_1 is followed by T_2, and the maximum unambiguous velocity is $\lambda / 4(T_1 - T_2)$
  - The advantage is that the effective period is $T_1 - T_2$

ACERAD Operation

- Staggered PRF, 7.7 and 5.6 kHz (same across Ka-band swath, since change in range is negligible, 270 m difference between nadir and edge)
- HH-VV polarization with option to add phase coding if additional isolation between H and V channels is needed
  - Alternating pulses, transmit H, V, H, V, … and receive same pulse (after delay corresponding to 5 msec round-trip time)
- Continuous (non-burst) operation
- Form lag-0 (power) by accumulating separate sums of $|H|^2$ and $|V|^2$
- Form lag-1 (Doppler) by accumulating separate sums of H^*V and V^*H
- Form lag-2 by accumulating H*H and V*V as a single sum = Σ r(i)*r(i+2), where r(i) is the ith received pulse (H or V)
  - This is used to get the HH-VV correlation coefficient

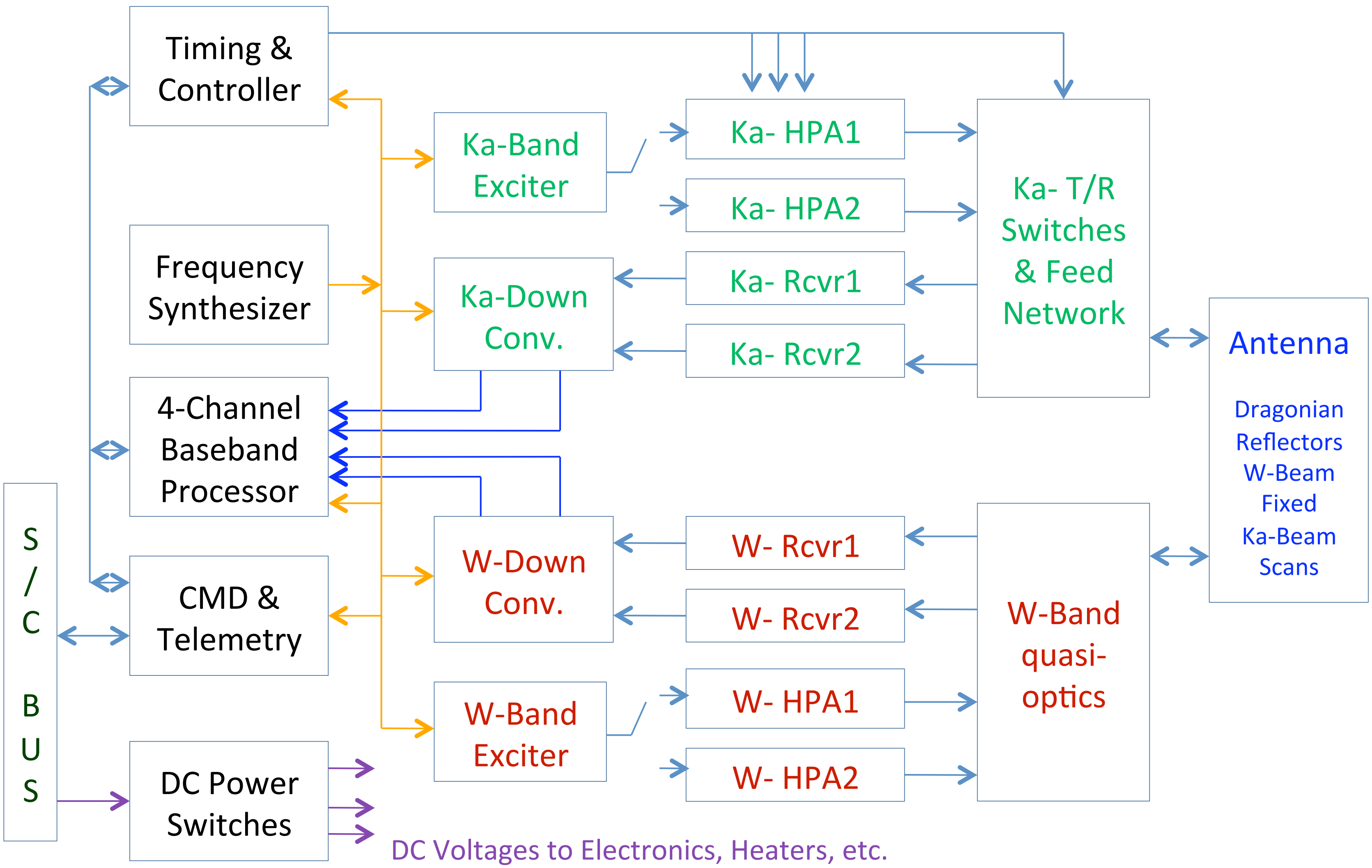


Estimated Performance



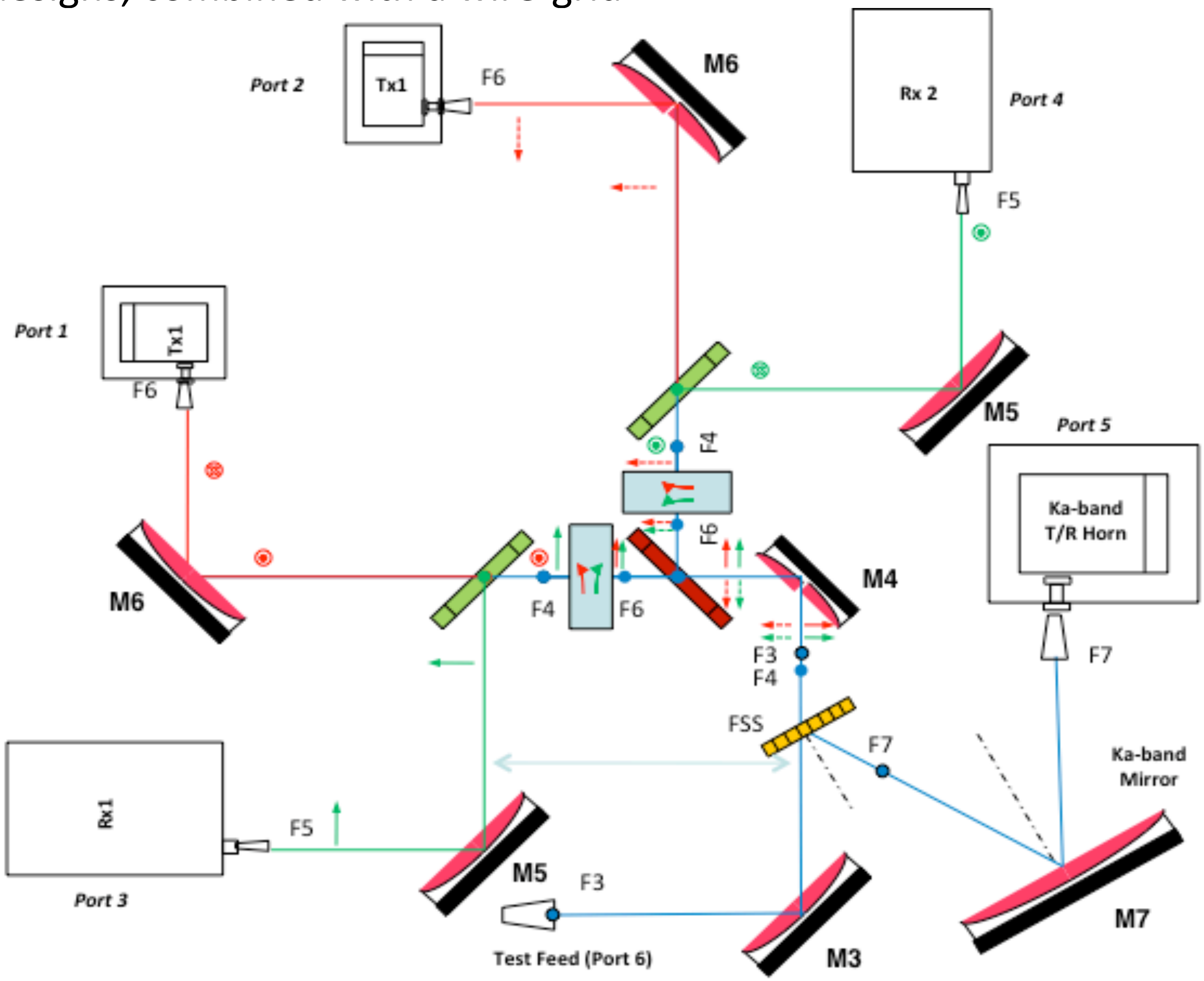
ACERAD Instrument Implementation

- Common receiver to save mass/power
- Each channel separated by 5 MHz to minimize interference between channels



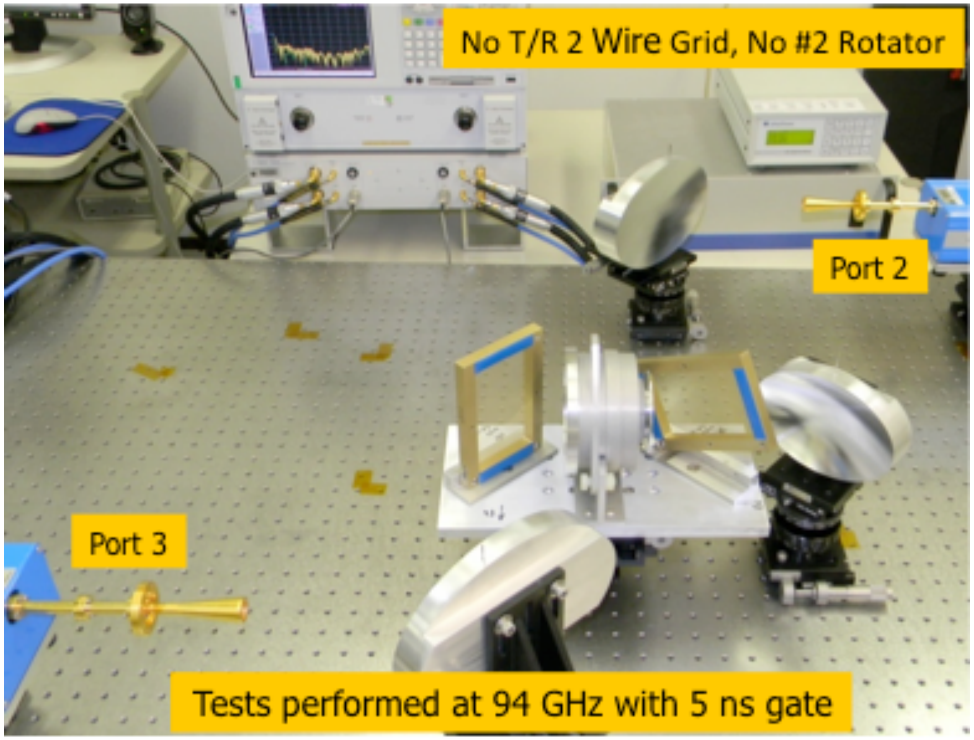
W-band Quasi-Optics

- Dual-polarization quasi-optics is implemented with two CloudSat-like designs, combined with a wire-grid



Dual-pol Quasi-Optics Testing

- Example results: isolation between H-pol transmit and V-pol receiver



Port 3 pol	Port 2 pol	S_{32} (dB)	S_{23} (dB)
↑	↖	53.6	52.3
→	↖	62.0	62.0

Dual-pol Quasi-Optics Results

- Key measured values are shown in the table below.
- More measurements need to be taken to verify the numbers.
- These preliminary measurements indicate that the system works as a dual-polarization, transmit/receive switch, as designed.

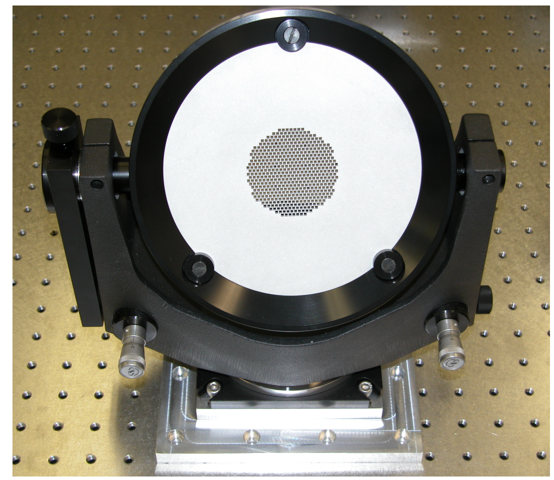
T→ R↓	Port 1 **Tx1**	Port 2 **Tx2**	Port 3 **Rx1**	Port 6 **Ant.**
Port 1 **Tx1**			60	40
Port 2 **Tx2**			50	3.0
Port 3 **Rx1**	80	50		2.0
Port 6 **Ant.**	3.5	3.0	8.5	

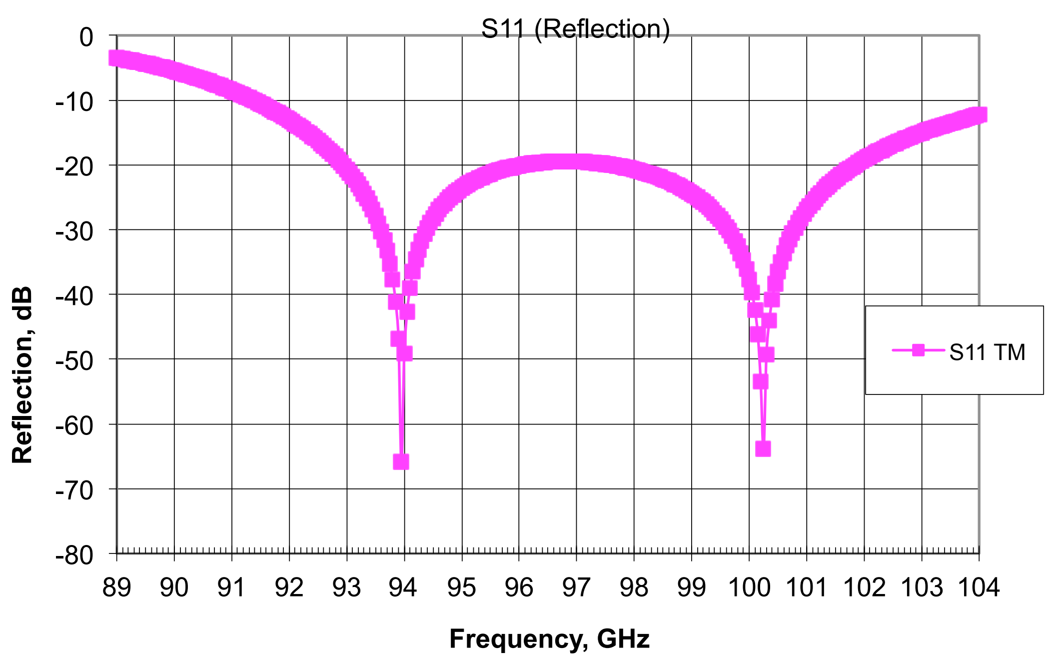
Note 8.5 dB coupling is due to incorrect thickness of ferrite; Incorrect rotation results in extra reflection from wire grid

Expect much lower loss with correct rotation

W-/Ka-band Separation: Dichroic Plate

- Designed and fabricated dichroic plate (frequency selective surface) to separate/combine Ka-/W-band signals
- Analyzed for multipactor problems
  - Found near 30 dB margin
  - Multipactor not a problem
- Performed MOM calculations of performance
- Carried out laboratory testing



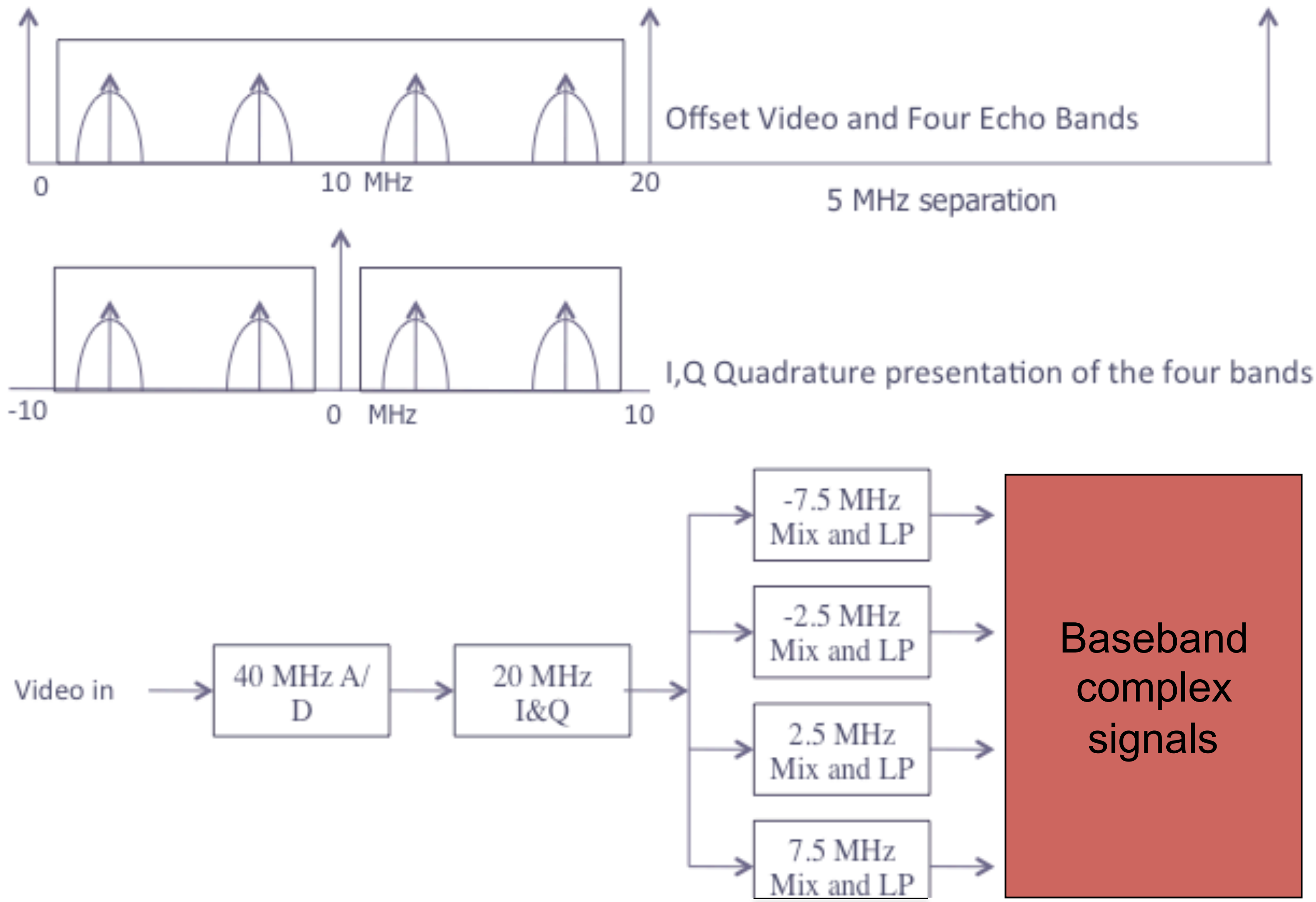


Measured resonances agree with calculated resonances to better than 1%

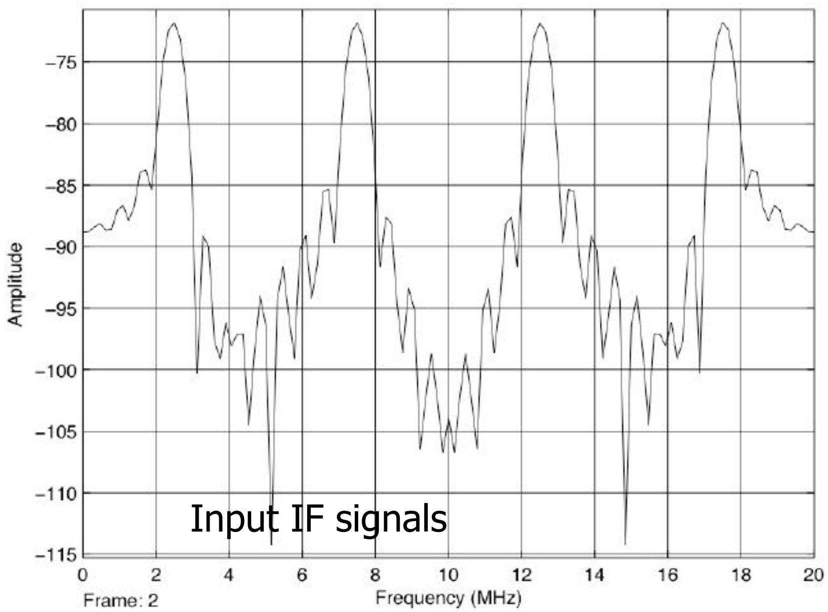
Currently working on thermal and vibe testing

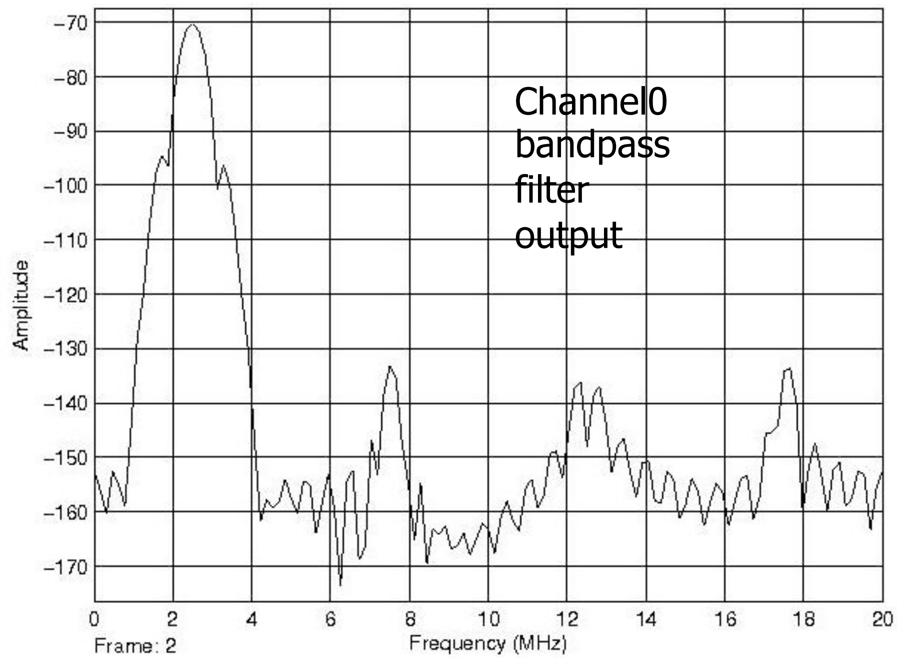
Receiver Back-end

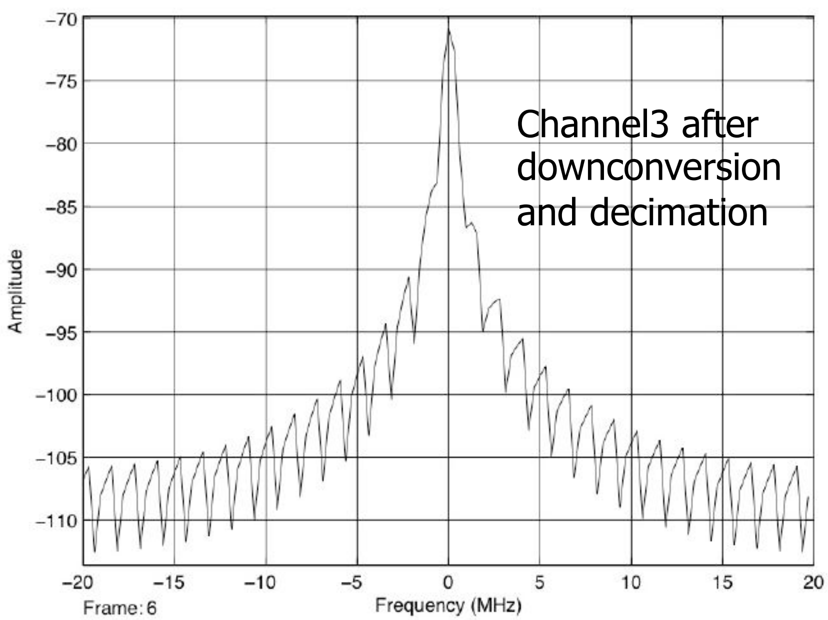
- Single receiver; channels separated in frequency to eliminate interference
- One ADC is used to capture all four channels

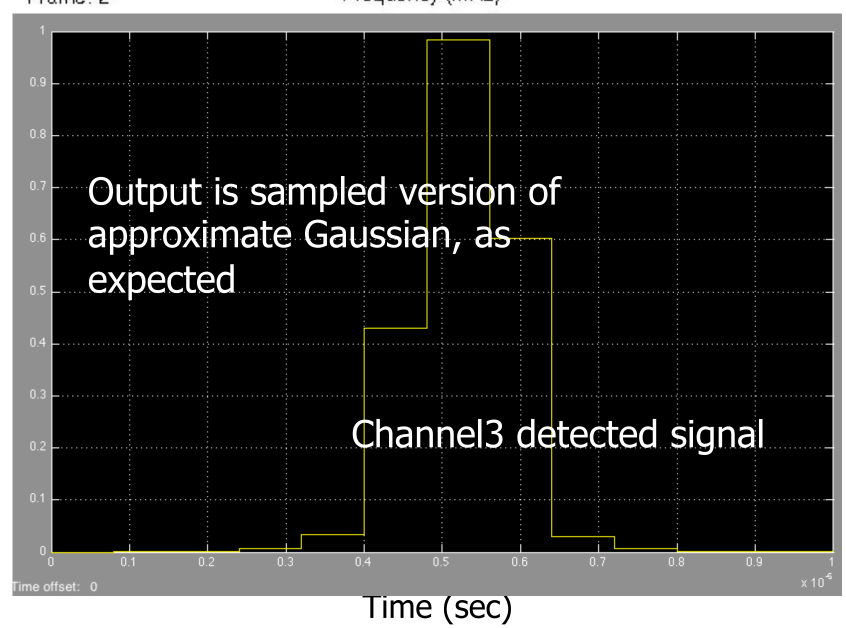


Simulink Output



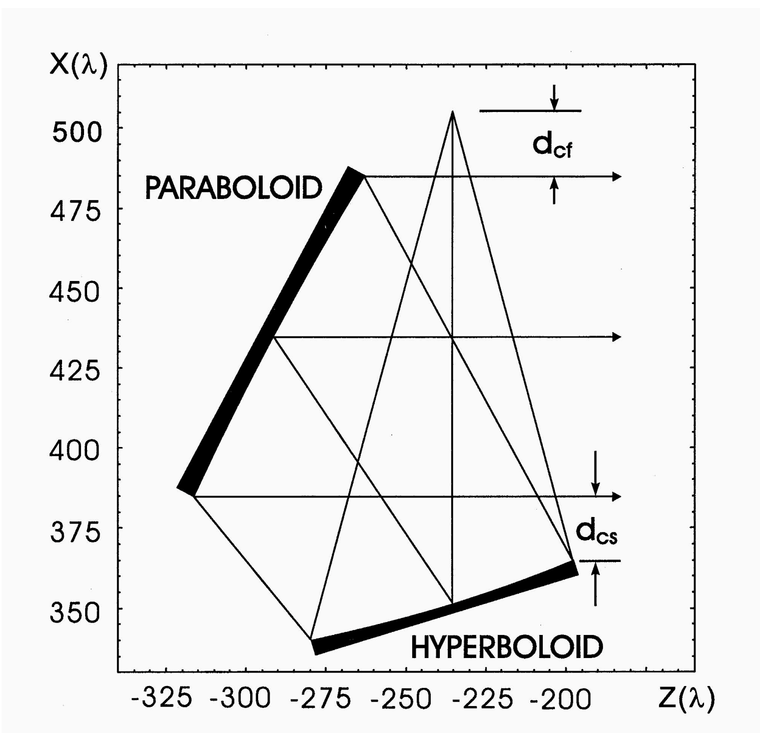


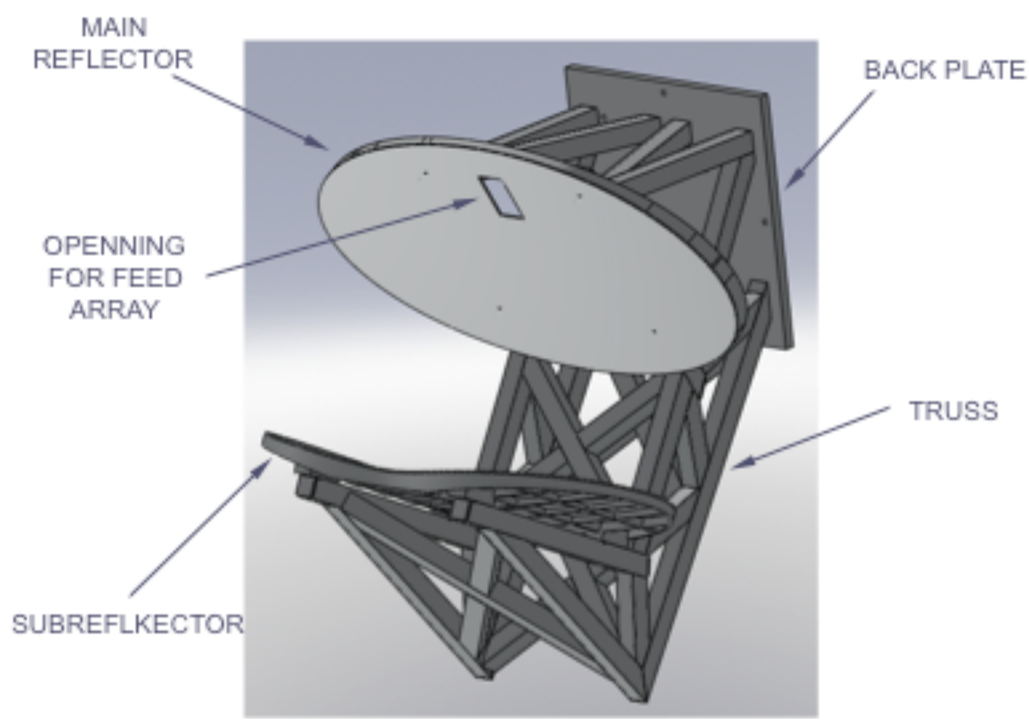




Antenna

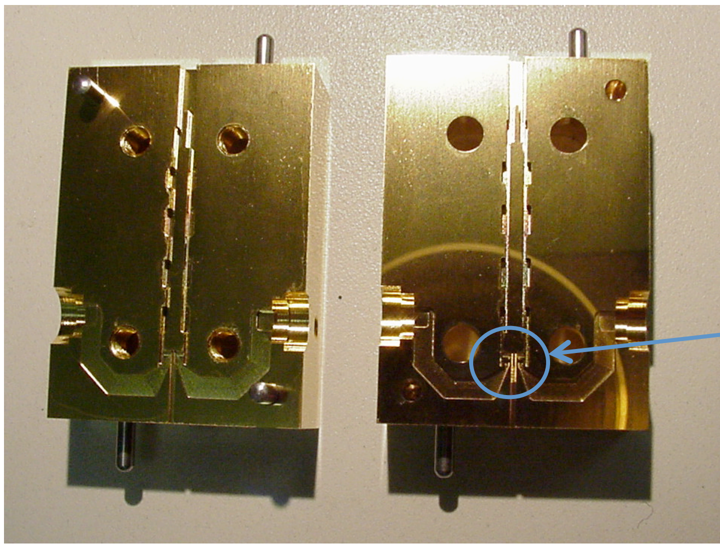
- Antenna is a 2.5 m x 5 m Dragonian design to allow limited scanning, currently planned at Ka-band only
- Currently building scaled prototype for range testing (1.25 m x 0.625 m)
- Antenna testing will be done at 94 and 280 GHz to simulate 35/94 GHz operation of full-sized antenna



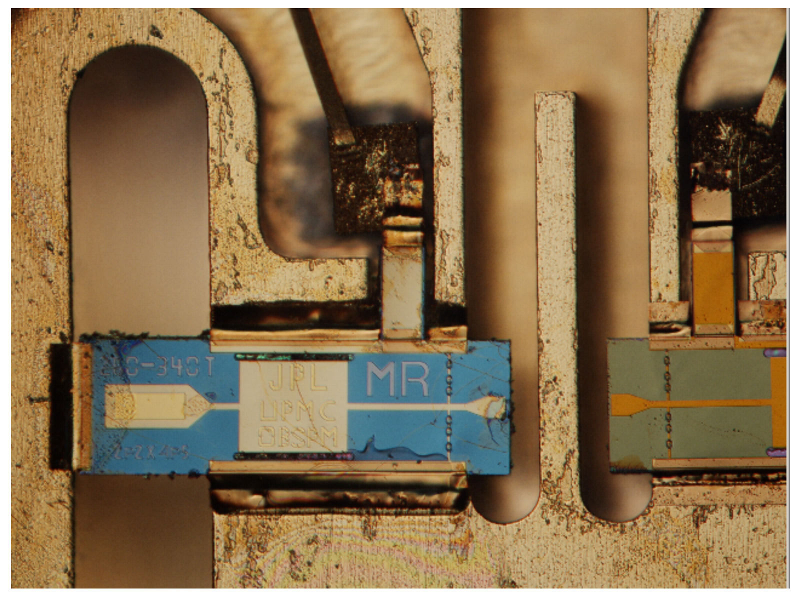


280 GHz Power Amplifiers

- GaAs Schottky diodes investigated for use in future radar system
- More immediate use is scaled testing of prototype antenna
- Power levels of 30 mW with power-combined tripler



Devices reside here



Comparison of ACERAD with Other Approaches

- There have been several other architectures considered for the ACE radar
  - Rebuild of CloudSat W-band radar
  - Rebuild of CloudSat W-band radar plus new Ka-band radar
  - Combined reflector/reflectarray
  - Cylindrical reflector with dual-freq line feed (PR-2 style, IIP' 99)

	CloudSat	CloudSat + Ka-band	ACERAD	Reflect-array	Cylindrical Parabolic
Dual-freq					
Ka-band scan			30 km	140 km	>100 km
W-band scan					>75 km
Size/wt					
TRL	9	4-9	4-9	3-4	3-4

Summary and Conclusions

- High-level system design complete
  - Have also completed high-level RF design and preliminary component selection (with TRL assessment)
  - Will complete mechanical layout by end of task
- W-band quasi-optics tested with good performance
  - Plan to repeat tests with updated components
- Dichroic has been designed, fabricated, and tested
  - Test results match calculated performance
  - Currently working on vibe and thermal testing with completion expected by end of summer
- Brunt of remaining work is in fabricating prototype antenna and feed and in testing at 94 and 280 GHz

Backup

ACERAD Performance vs. Science Reqts

	PARAMETER	UNIT	REQUIREMENT	GOAL (#Priority)	ACERAD	Comment
W-band, nadir	Min Det Sens	dBZ	-35	-40 (#3)	-35	EarthCARE level of detection.
	Doppler Acc	m/s	0.4	**0.2(#2)**	0.2	Precipitating/non-precipitating, sedimentation, cloud scale entrainment.
	Vert Res	m	250	**100 (#1)**	250	Melting layer, geometrically thin clouds, in-bin attenuation.
	Sfc Cltr max hgt	m	500	**250 (#1)**	400	Cloud base vs surface precipitation.
	Hor Res	km	1 x 1	--	0.7 x 1	CRM scale.
	Polarimetry (LDR)		--	YES (#5)	YES	Mixed phase and multiple scattering.
W-band, off-nadir	Swath Width	km	--	≥2 (#4)	--	Convective cell resolution (10km), radiometer footprint (25km). Ka-radar footprint (2km)
	Min Det Sens	dBZ	--	-20	--	All light precipitation, most large particle clouds.
	Doppler Acc	m/s	--	1	--	
	Vert Res	m	--	250	--	
	Hor Res	km	--	1 x 1	--	
Ka-band, nadir	Min Det Sens	dBZ	-10	**-20 (#2)**	-12	Most (all) light precipitation, some (all) large particle clouds.
	Doppler Acc	m/s	1	0.5 (#3)	0.5	Rain/no rain, convection.
	Vert Res	m	250	100 (#4)	250	
	Sfc Cltr max hgt	m	500	250 (#4)	400	
	Hor Res	km	2 x 2	1 x 1	1.8 x 1	CRM scale / matched beam.
	Polarimetry (LDR)		--	YES (#5)	YES	
Ka-band, off-nadir	Swath Width		--	**>25 (#1)**	33	Convective cell resolution, radiometer footprint. 100km would achieve meso-scale features.
	Min Det Sens	dBZ	--	-10	-10	
	Doppler Acc	m/s	--	1	1	
	Vert Res	m	--	250	250	
	Hor Res	km	--	2 x 2	1.8 x 1	

Ka-band Antenna Scan Design

- Uses Ka-band dual-polarized compound-flare rectangular corrugated horn focal plane array
- Produces -2.4° to +2.4° of scan on the Y=0 plane
- Adjacent beams are spaced by 1 Ka-band HPBW (i.e., 0.22°)
- The Ka- and W-band 0° beams access the QOTL through array center opening
- For prototype, a single corrugated feed is being developed
  - will be physically moved for scan